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FIELD ASSESSMENT OF THE CALIFORNIA GAP ANALYSIS PROGRAM DATABASE FOR SAN DIEGO COUNTY

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ABSTRACT

Given the key role played by biogenic hydrocarbons (BHC's) in photochemical smog formation and atmospheric chemistry, it is critical to generate accurate BHC emission inventories. Assembling such inventories requires reliable characterization of the areal coverage of important plant species in order to quantify the biomass of BHC-emitting vegetation. A recent GIS-based description of vegetation coverage in the natural areas of San Diego County is provided by the Gap Analysis Program (GAP) database. We conducted an assessment of this database through ground-based vegetation surveys prior to using the database to develop a BHC emission inventory for southern California. Quantitative vegetation surveys were conducted along belt transects in four polygons dominated by trees and along line transects in four polygons dominated by shrubs, in order to determine percent cover of major plant species. The species listed by GAP accounted for two-thirds to three-quarters of the relative cover in these selected polygons. About 60% of the species listed by GAP were found in high enough proportions in the field surveys to justify their listing. Summed over all eight polygons, BHC emission indices based on GAP data correlated with BHC emission indices generated with data from our field surveys. On balance, we judge the GAP GIS database to be a useful source of species composition and dominance information for the purpose of assembling BHC emission inventories, provided supplementary data on crown volumes are available from the literature or can be obtained in the field.

The emission of reactive hydrocarbons such as isoprene and monoterpenes by vegetation (i.e., biogenic hydrocarbons or BHC's) has been known for several decades (Went 1960; Rasmussen 1972). However, only in the last fifteen years has interest in the role of BHC's in photochemical smog formation and atmospheric chemistry expanded dramatically, both in the scientific and regulatory communities (Winer et. al. 1983; Lamb et al. 1987; Chamedies et al. 1988; NRC 1991; Corchnoy et al 1992; Winer et al. 1992; Arey et al. 1995; Geron et al 1995; Sharkey and Singsaas 1995; Benjamin et al. 1996, 1997; Guenther 1997; Benjamin and Winer 1998).

In the atmosphere, many BHC's are as reactive as, or more reactive than, volatile organic compounds (VOC) emitted from mobile or stationary anthropogenic sources (Carter 1994; Benjamin and Winer 1998), and there is a growing body of research suggesting BHC's can constitute a significant and even dominant contribution to the overall VOC inventory in both regional airsheds and the global atmosphere (Workshop on Biogenic Hydrocarbons [WBH] 1997). Given the enormous costs associated with further reducing VOC and NO_X emissions to meet state and federal air quality standards, it is critical to obtain data needed to assemble reliable BHC emission inventories, including composition and dominance of the plant species in an airshed, green leaf biomass for the dominant plant species, and quantitative rates of emission of individual organic compounds from these species.

Plant species distributions, BHC emission rates, and leaf mass constants have been developed for a substantial number of species relevant to certain areas of California (Winer et al. 1983, 1992; Miller and Winer 1984; Horie et al. 1991; Karlik and Winer 1998). With the proposal of a taxonomic methodology for assigning isoprene and monoterpene emission rates to unmeasured plant species (Benjamin et al. 1996), emission rates can in principle be estimated for many of the 6000 plant species in California without direct experimental measurements. Of the southern California airsheds, the vegetation spatial distribution and composition has been established for urban and natural areas within Orange County and the non-desert portions of Los Angeles, Riverside, and San Bernardino Counties (Winer et al. 1983; Miller and Winer 1984; Horie et al. 1991; Benjamin et al. 1997), and a limited BHC emission study for Santa Barbara and Ventura Counties has also been reported (Chinkin et al. 1996). However, a validated inventory of vegetation species composition and spatial distribution, specifically to develop a BHC emissions inventory, has not been established for the San Diego County airshed.

A potential source of information concerning vegetation in the natural areas of San Diego County is the Gap Analysis Program database (GAP), which is coordinated by the United States Geolog-

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ical Service–Biological Resources Division (formerly the National Biological Service) to identify the distribution and management status of plant communities. GAP compiled a geographic information system (GIS) database (based primarily on remote-sensing data) describing vegetation type and dominance in terms of areal coverage (Davis et al. 1994, 1995). Unlike other vegetation maps, which describe geographic areas using only plant communities, the California GAP describes vegetation in given geographic areas using dominant plant species. Because BHC emissions inventories rely on species-specific measurements of both leaf mass and BHC emission rates (Benjamin et al. 1997), GAP offers the advantage of providing species-specific vegetation distribution data. Moreover, the GAP GIS database is recent for southern California (Davis et al. 1995) and therefore more up to date than older vegetation databases employed in California, such as the vegetation type map (VTM) surveys conducted in the 1930's and CALVEG generated in the 1970's (Sawyer and Keeler-Wolf 1995). Although large-area, small-scale GIS databases based on remote-sensing data, such as GAP, offer a potentially inexpensive and simple approach to characterizing the distribution and species identity of natural vegetation within an airshed, use of such GIS databases in BHC emissions inventory development requires evaluation of their accuracy and reliability through ground-based observations.

We report here the results of a ground-based assessment of the GAP GIS database for San Diego County using vegetation surveys of representative GIS polygons. The surveys employed a modified stratified random sampling approach and a survey protocol based in part on the recommendations of the developers of the GAP database (Stoms et al. 1994). Data gathered from field surveys conducted from September 1997 to April 1998 in San Diego County were used to assess the utility of the GAP GIS database for predicting the distribution and species identity of vegetation, and for providing a quantitative description of plant species assemblages.

Methods

Gap analysis program database. As noted earlier, GAP's purpose was to identify the distribution and management status of selected components of biodiversity. The central tool of this program was an ARC/INFO GIS database with plant species and vegetation class attributes associated with polygons within a defined geographic region. This database was generated from summer 1990 Landsat Thematic Mapper satellite imagery, 1990 high altitude color infrared photography, VTM surveys based on field surveys conducted between 1928 and 1940, and miscellaneous vegetation maps and ground surveys (Davis et al. 1995). Polygons were delimited based on climate, physiography, substrate, and disturbance regime. Landscape boundaries were subjectively determined through photointerpretation by expert personnel so that between-polygon variation was greater than within-polygon variation. The final result was a vegetation map with a 100 hectare minimum mapping unit and a 1:100,000 mapping scale (Davis et al. 1995).

For each polygon in the database, one primary and one secondary vegetation assemblage was listed. Each assemblage consisted of three co-dominant overstory species, each covering a minimum of 20% of the relative cover of the assemblage. The primary assemblage was defined as the assemblage covering the majority of the polygon, and the secondary assemblage as covering the remainder of the polygon. Relative cover is the proportion of total vegetation cover occupied by a given plant species, excluding certain vegetation such as plants below a pre-established height and bare ground. Overstory plants are those plants viewable directly from above. In addition, GAP listed the percent crown cover of each assemblage in the polygon in four classes.

Acquisition and preparation of the GAP database. The GAP database for the southwest ecoregion was obtained in August 1997 from the Department of Geography at the University of California at Santa Barbara. The southwest ecoregion covers all or portions of Santa Barbara, Ventura, Kern, Los Angeles, San Bernardino, Orange, and Riverside Counties and the western two-thirds of San Diego County. The remaining eastern third of San Diego County is located in the Sonoran ecoregion, which was not obtained for use in the present study because it is located far from the major urbanized centers of San Diego County, and because the ecoregion is composed mostly of deserts with little biomass. From the 2014 original polygons for the southwest ecoregion, the San Diego County subset of 437 polygons was extracted using ArcView 3.0a GIS software.

Vegetation survey protocol and methods. The vegetation survey protocol employed was initially based on recommendations for a GAP database validation study suggesting 1 square km sample units (Stoms et al. 1994). Because the GAP database is a large-area land cover map, use of a large sample element (e.g., 1 km^2) avoids quantifying heterogeneity below the intended resolution of the map. Stoms et al. (1994) noted other issues affecting vegetation surveying such as the need to obtain legal access from private land-owners, safety, and proximity of sample sites to roads. The specific shape of the vegetation survey unit was left unresolved in the guidelines.

In the present study, the specific survey protocol chosen depended on the type of vegetation being assessed. Within the polygons dominated by trees, surveys were performed in three sample elements consisting of two 6 m wide, 500 m long belt transects bisecting each other at right angles. Other researchers have demonstrated 6 m wide belt transects make the mechanics of sampling easier while not significantly compromising accuracy (Lindsey 1955). For these belt transects, the surveyors walked 250 m north, south, east, or west away from the centerpoint, using a magnetic compass to maintain course.

In the present study, one person measured the crown radii and diameter at breast height of trees and the crown height of shrubs (plants with more than one stem), while another measured the crown height of trees (plants with one stem) and recorded the field data. Crown radii in trees were measured with a 10 m tape in four directions (north, south, east, and west). Crown radii in shrubs were measured using two diameters perpendicular to each other. Readings were taken to the nearest tenth of a meter. Crown height of trees was obtained from a clinometer. From a distance of approximately 10–20 meters, the observer measured to the nearest meter the distance from the tree to the observer using an optical rangefinder. With a clinometer, the observer determined the crown height as a percentage of the observer's distance away from the tree.

Within polygons dominated by scrub or chaparral, one individual performed surveys in four sample elements, each consisting of two 300 m long line transects bisecting each other at right angles. Line transects have been used to estimate relative cover for chaparral (Bauer 1943) and for sage scrub (Kent and Coker 1992; Zippin and Vanderwier 1994). The individual surveyed along line transects using a 50 m tape and collected data on the identity of the topmost plant species directly over the meter tape, was determined the number of 0.1 m segments occupied by that plant species, and recorded the height of the crown for each individual plant to the nearest 0.1 m. The crowns were envisioned as rectangular prisms and measured as such. The 150 m transects running north, south, east, and west from the centerpoint were completed using three 50 m segments.

The survey team located the centerpoint of a particular sample element using a global positioning receiver (GPS) locked onto universal transmercator (UTM) coordinates gathered from the GAP database. A Garmin 12XL handheld GPS unit, with an accuracy of ± 100 m 99% of the time, was employed. The survey team then recorded the species identity and related data as described above. For forested polygons (areas where crowns of trees interlocked), only data from plants taller than waist height were recorded. For woodland polygons (areas where crowns of trees did not interlock), only plants taller than knee height were recorded. For scrub and chaparral, all plant species except for understory species and grasses were recorded. All plants were identified in the field, and samples of unidentifiable plants were taken to the herbarium at UCLA for identification.

Selection of polygons from the GAP database. Polygons were chosen for potential inclusion in the present study based on an index estimating their isoprene or monoterpene emissions. Use of these indices identified eighty polygons (Fig. 1) estimated to have the largest biogenic hydrocarbons emissions based on the presence of high-emitting plant species (Benjamin et al. 1996) and their areal coverage within a polygon.

Further selection from among the eighty polygons with the highest BHC emissions involved an iterative process accounting for representativeness and feasibility. In considering representativeness, roughly equal numbers of polygons were selected with woodland/forest vegetation and scrub/chaparral vegetation, the two main classes of natural vegetation in San Diego County. Polygons were selected to insure that all geographic regions of the county, except the desert regions, were represented. In considering feasibility, physical access and permission to survey vegetation on private or military property were important. Polygons with a large public land component (e.g., California State Parks, San Diego County Parks, United States National Forest System, Bureau of Land Management, and local parks) were favored due to the relative ease of gaining permission to conduct surveys on such properties compared with privately-owned properties.

The minimum square-shaped area needed to encompass a sample element within a polygon was determined to be 62.5 acres for forests and woodlands and 22.5 acres for scrub and chaparral, and owners of parcels of land of these sizes within selected polygons were identified using information from the San Diego County assessor's records. A letter was prepared requesting permission to conduct a vegetation survey, stating the goals of the research, and enclosing a form to be returned offering or denying access. Out of 69 mailers, 10 owners agreed to participate in the study, 15 declined and the rest were non-responders, for a success rate of about 14%. Those polygons with a large public land component and/or with many private land owners responding positively to the mailers were included for further consideration.

Based on these criteria and the time and resources available for this research, eight polygons were selected for the present study. Four polygons consisted primarily of woodland/forest vegetation, and four polygons consisted primarily of shrub/chaparral vegetation (Table 1). Of these eight polygons, five were estimated to be dominated by isoprene emissions, two were estimated to be dominated by monoterpene emissions, and one exhibited both high isoprene and high monoterpene emissions. Table 1 lists data for each of these eight polygons according to the GAP database, including the expected species assemblages and their relative proportion of the polygon and crown closure. In addition, Table 1 lists the polygon rank by the iso-

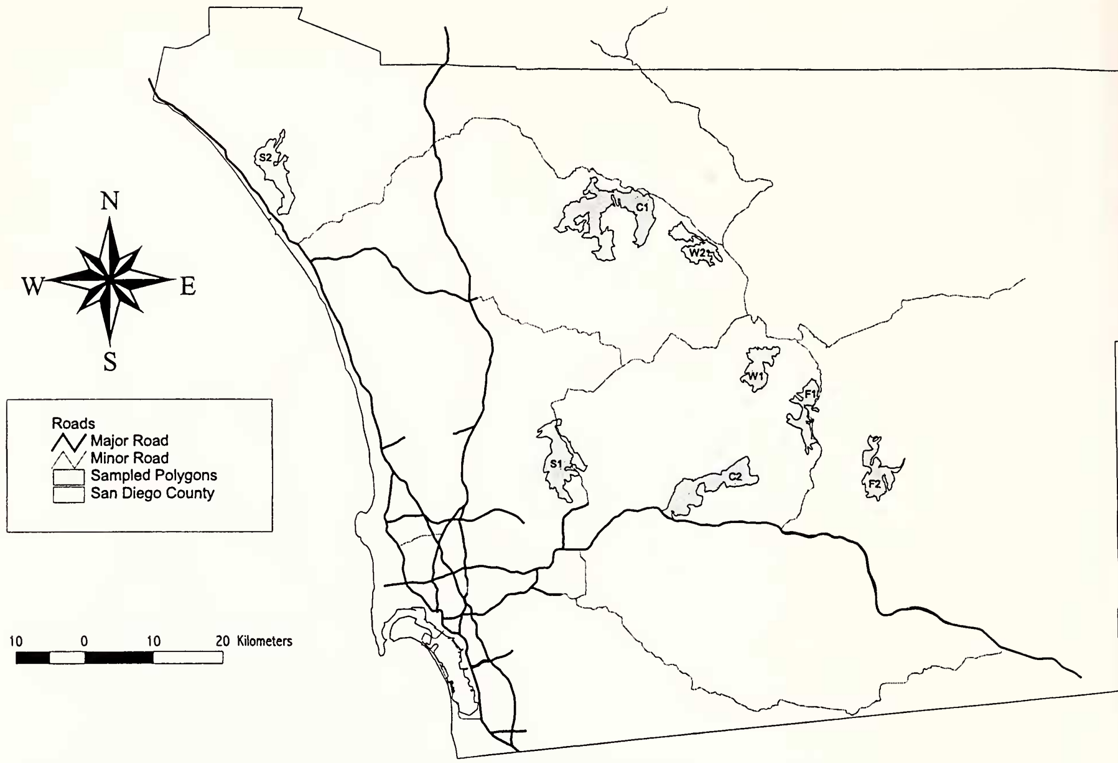

FIG. 1. GAP polygons surveyed in San Diego County for plant species composition and dominance.

prene or monoterpene emission index. Figure 1 shows the location of the polygons investigated in the present study.

Selection of sample elements within a polygon. After a polygon was chosen by the process described above, sample elements were selected. The centerpoints of the elements were located so all transects were at least 100 meters away from the polygon boundary. If permission was obtained to access most of the polygon, sample elements were selected by overlaying a 500 meter UTM grid on the polygon, assigning sequential numbers to every grid element within 1 km of a road, and randomly selecting the needed number of 500 meter grid elements. This method was similar to the one employed in the Utah GAP validation project (Edwards et al. 1995). Only four polygons had enough area accessible by roads or sufficient permission to be sampled. For the other four polygons, large portions were physically or legally inaccessible, and sample elements were chosen from within the accessible areas. To minimize bias in site selection for these four polygons, the final selection of sample elements was decided before entry into the polygon. In several cases, suitable survey sites were not available within the vicinity of a road, so hikes of up to two hours along a trail were needed to reach the desired area within the polygon.

Data analysis. As noted earlier, the GAP GIS database provides semi-quantitative information on the abundance and distribution of plant species. For each polygon, the GAP database lists species assemblages and the estimated areal proportion (p) of that assemblage within a polygon. Each species in a listed assemblage is a co-dominant, providing ≥20% relative cover. The expected relative cover of a species listed in the GAP database for a polygon is then ≥0.2p. For example, in polygon F1, *Quercus agrifolia* Nee is a co-dominant in an assemblage that occupies 60–70% of the polygon. Using a mean value of 65%, GAP predicts *Q. agrifolia* would cover ≥ 13% of the polygon.

The relative cover of plant species inferred from the GAP database by this procedure was compared with the cover data gathered from the field surveys in the eight selected polygons. First, the relative cover of each species within each sample element of a polygon was calculated. Then from the species relative cover for each sample element, the mean relative cover and upper limit of the two standard error (SE) confidence interval for the polygons were calculated, corresponding to an 85% confidence interval (McClave and Dietrich 1985).

If the upper limit of the confidence interval for the relative cover of a measured species was less than its GAP-predicted relative cover, then the species was considered an "incorrect" listing as a co-

TABLE 1. POLYGONS FROM THE GAP DATABASE SELECTED FOR FIELD SURVEY OF SPECIES COMPOSITION AND ABUNDANCE. [a] From GAP database (University of California at Santa Barbara Department of Geography 1997). [b] F = Forest, W = Woodland, C = Chaparral, S = Sage Scrub. [c] Ii = Isoprene emission index. [d] Im = Monoterpene emission index.

ID[b]	Area (ha)[a]	Primary or secondary[a]	Species assemblage[a]	Percentage of polygon[a]	Crown closure[a]	Rank by I_I[c]	Rank by I_M[d]
F1	1990	P	*Quercus kelloggii, Quercus chrysolepis,* and *Quercus agrifolia*	60–70%	60–100%	10	159
		S	*Pinus lambertiana, Pinus coulteri,* and *Libocedrus decurrens*	30–40%	60–100%		
F2	2317	P	*Quercus kelloggii* and *Pinus jeffreyi*	50–60%	40–59%	29	136
		S	*Quercus cornelius-mullerii, Cercocarpus betuloides,* and *Adenostoma fasciculatum*	40–50%	60–100%		
W1	1904	P	*Quercus agrifolia, Quercus engelmannii,* and *Quercus kelloggii*	60–70%	25–39%	9	170
		S	*Ceanothus leucodermis, Adenostoma fasciculatum,* and *Quercus berberidifolia*	30–40%	60–100%		
W2	1778	P	*Quercus kelloggii, Quercus agrifolia,* and *Quercus engelmannii*	60–70%	60–100%	16	249
		S	*Adenostoma fasciculatum, Arctostaphylos tomentosa,* and *Cercocarpus betuloides*	30–40%	60–100%		
C1	6578	P	*Quercus berberidifolia* and *Ceanothus leucodermis*	50–60%	60–100%	7	37
		S	*Adenostoma fasciculatum, Cercocarpus betuloides,* and *Ceanothus* sp.	40–50%	60–100%		
C2	3986	P	*Adenostoma fasciculatum, Quercus berberidifolia* and *Ceanothus leucodermis*	80–90%	60–10%	20	56
		S	*Ceanothus greggii* and *Arctostaphylos pungens*	10–20%	60–100%		
S1	3650	P	*Artemisia californica, Eriogonum fasciculatum,* and *Salvia apiana*	60–70%	40–59%	102	8
		S	*Adenostoma fasciculatum, Ceanothus oliganthus,* and *Quercus berberidifolia*	30–40%	40–59%		
S2	2718	P	*Artemisia californica, Salvia mellifera,* and *Malosma laurina*	80–90%	60–100%	251	2
		S	*Avena* spp., *Bromus* spp., etc. and *Baccharis pilularis*	10–20%	25–39%		

dominant in the GAP database. Otherwise, it was considered a "correct" listing. An observed species not listed by GAP as a co-dominant was considered a "potential" co-dominant if the upper limit of the uncertainty interval was greater than the predicted relative cover value of any co-dominant in the secondary assemblage in that polygon. For example, in polygon F1, the smallest predicted relative cover is that of a co-dominant in the secondary assemblage which provides 30–40% cover for that polygon. Using a mean value of 35% for the secondary assemblage in polygon F1 and a relative cover value of ≥20% for a co-dominant, then ≥7% of the polygon is expected to be covered by a co-dominant of a secondary assemblage in polygon F1. Any plant species not listed by GAP but observed in polygon F1 with a relative cover ≥ 7% was considered a potential co-dominant in that polygon.

Crown closure from the GAP database was also compared to the field data. Crown closure is equivalent to the percent coverage by all overstory plants within a polygon divided by the area of the polygon. A confidence interval within two SE was calculated from these data and compared with the data predicted from the GAP database.

RESULTS

Species composition and abundance within GAP polygons. Table 2 summarizes the overall results from the field surveys, listing the six most abundant overstory species observed for each polygon, the percent composition predicted from the GAP database, the percent composition determined by the field surveys, and the upper limits of a two SE interval of the percent composition. In the forest and wooded polygons, overstory plants accounted for 87–92% of the relative crown cover according to

TABLE 2. MEASURED SPECIES COVER COMPOSITION OF THE SIX MOST ABUNDANT PLANT SPECIES OBSERVED IN SELECTED GAP POLYGONS. * Species listed in the GAP database as a co-dominant, but not ranked in the top 6 species observed for the polygon.

Polygon	Species	Predicted cover (%)	Sampled cover (%) (s)	(s + 2 SE)
F1	*Quercus chrsyolepis*	≥13	23	70
	Pinus jeffreyi	—	19	47
	Quercus kelloggii	≥13	19	26
	Quercus agrifolia	≥13	11	24
	Arctostaphylos pungens	—	7	17
	Pinus coulteri	≥7	6	18
	**Calocedrus decurrens*	≥7	4	7
	**Pinus lambertinana*	≥7	0.0	—
	Total of six highest		85	
	GAP Co-dominants		64	
F2	*Quercus kelloggii*	≥11	34	37
	Pinus jeffreyi	≥11	18	39
	Quercus berberidifolia	—	13	23
	Ceanothus palmeri	—	11	26
	Cercocarpus betuloides	≥9	7	14
	Adenostoma fasciculatum	≥9	5	12
	**Quercus cornelius-mulleri*	≥9	0.0	—
	Total of six highest		88	
	GAP Co-dominants		65	
W1	*Quercus engelmannii*	≥13	39	56
	Quercus agrifolia	≥13	26	41
	Arctostaphylos gladulosa	—	10	27
	Adenostoma fasciculatum	≥7	8	25
	Salvia apiana	—	4	12
	Eriogonum fasciculatum	—	4	11
	**Quercus kelloggii*	≥13	2	3
	**Ceanothus leucodermis*	≥7	0.2	2
	Quercus berberidifolia	≥7	0.0	—
	Total of six highest		91	
	GAP Co-dominants		76	
W2	*Quercus engelmannii*	≥13	62	121
	Quercus kelloggii	≥13	17	46
	Quercus berberidifolia	—	10	27
	Quercus agrifolia	≥13	3	6
	Pinus coulteri	—	2	6
	Arctostaphylos glandulosa	—	2	4
	**Adenostoma fasciculatum*	≥7	1	3
	**Cercocarpus betuloides*	≥7	.05	1
	Arctostaphylos glandulosa	≥7	0	—
	Total of six highest		96	
	GAP Co-dominants		85	
C1	*Quercus berberidifolia*	≥11	39	67
	Adenostoma fasciculatum	≥9	36	54
	Eriogonum fasciculatum	—	5	15
	Quercus engelmannii	—	4	12
	Ceanothus crassifolius	—	2	4
	Heteromeles arbutifolia	—	2	4
	**Cercocarpus betuloides*	≥9	2	4
	**Ceanothus leucodermis*	≥11	0.4	1
	*Buckbrush	≥9	0.0	—
	Total of six highest		88	
	GAP Co-dominants		78	
C2	*Adenostoma fasciculatum*	≥17	51	73
	Xylococcus bicolor		13	25
	Eriogonum fasciculatum		8	15
	Quercus berberidifolia	≥17	5	6
	Malosma laurina		4	9
	Rhus ovata		4	7
	**Ceanothus greggii*	≥3	3	7
	**Ceanothus leucodermis*	≥17	1	1
	Total of six highest		85	
	GAP Co-dominants		59	
S1	*Eriogonum fasciculatum*	≥13	26	49
	Adenostoma fasciculatum	≥7	21	48
	Artemisia californica	≥13	20	33
	Malosma laurina	—	14	26
	Xylococcus bicolor	—	6	14
	Ceanothus oliganthus	≥7	3	10
	**Quercus berberidifolia*	≥7	1	3
	Salvia apiana	≥13	1	1
	Total of six highest		90	
	GAP Co-dominants		72	
S2	*Artemisia californica*	≥17	41	68
	Salvia mellifera	≥17	16	31
	Malosoma laurina	≥17	14	24
	Rhus integrifolia	—	6	15
	Baccharis pilularis	≥3	4	12
	Malacothamnus fasciculatus	—	4	10
	Total of six highest		85	
	GAP Co-dominants		75	

our data. In the polygons dominated by scrub and chaparral, there was little or no understory.

Most of the relative cover was attributable to a few species. For all polygons, the six most abundant species (many of them listed as GAP co-dominants) were responsible for over 80% of the relative cover (Table 2). In general, the GAP co-dominants provided roughly two-thirds to three-quarters of the relative cover observed in the field surveys. For polygons F1, F2, W1, W2, C1, C2, S1, and S2, GAP co-dominants provided 64%, 65%, 76%, 85%, 78%, 59%, 72%, and 75% of the observed relative cover, respectively.

For both forest/woodland and chaparral/scrub polygons, the observed relative cover of certain co-dominants in GAP polygons often substantially exceeded the minimum predicted values (Table 2). For example, in polygon F2, *Quercus kelloggi* Newb. provided 34% of the relative cover when ≥11% was predicted, and in polygon W1, *Q. engelmannii* E. Greene provided 39% of the relative cover when ≥13% was predicted. In polygon C1, *Q. berberidifolia* Liebm. and *Adenostoma fasciculatum* Hook. & Arn. provided 39% and 36% of the relative cover, respectively, when ≥11% and ≥9% were predicted by the GAP database. Thus, although a lower limit for species relative cover can be inferred from the data provided by the GAP database, an upper limit for species relative cover is not available from GAP.

TABLE 3. SPECIES LISTED CORRECTLY AND INCORRECTLY AS CO-DOMINANTS WITHIN SURVEYED GAP POLYGON ORDERED BY DECREASING MEAN RELATIVE COVER. (p) GAP primary assemblage species. (s) GAP secondary assemblage species. * Potential co-dominant listed as a co-dominant in an adjacent GAP polygon. † See test.

Polygon	GAP species observed in significantly large quantities†	GAP species not observed in significantly large quantities†	Potential co-dominants
F1	*Quercus chrysolepis* (p) *Quercus kelloggii* (p) *Quercus agrifolia* (p) *Pinus coulteri* (s) *Calocedrus decurrens* (s)	*Pinus lambertiana* (s)	*Pinus jeffreyi** *Arctostaphylos pungens* *Quercus berberidifolia**
F2	*Quercus kelloggii* (p) *Pinus jeffreyi* (p) *Cercocarpus betuloides* (s) *Adenostoma fasciculatum* (s)	*Quercus cornelius-mulleri* (s)	*Quercus berberidifolia* *Ceanothus palmeri** *Pinus coulteri*
W1	*Quercus engelmannii* (p) *Quercus agrifolia* (p) *Adenostoma fasciculatum* (s)	*Quercus kelloggii* (p) *Ceanothus leucodermis* (s) *Quercus berberidifolia* (s)	*Arctostaphylos glandulosa** *Eriogonum fasciculatum** *Salvia apiana**
W2	*Quercus engelmannii* (p) *Quercus kelloggii* (p)	*Quercus agrifolia* (p) *Adenostoma fasciculatum* (s) *Arctostaphylos tomentosa* (s) *Cercocarpus betuloides* (s)	*Quercus berberidifolia**
C1	*Quercus berberidifolia* (p) *Adenostoma fasciculatum* (s)	*Cercocarpus betuloides* (s) *Ceanothus leucodermis* (p) *Ceanothus cuneatus* (s)	*Eriogonum fasciculatum** *Quercus engelmannii**
C2	*Adenostoma fasciculatum* (p) *Ceanothus greggii* (s)	*Quercus berberidifolia* (p) *Ceanothus leucodermis* (p) *Arctostaphylos pungens* (s)	*Xyloccocus bicolor** *Eriogonum fasciculatum** *Malosma laurina** *Rhus ovata* *Cneoridium dumosum* *Ceanothus oliganthus* *Arctostaphylos glandulosa**
S1	*Eriogonum fasciculatum* (p) *Adenostoma fasciculatum* (p) *Artemisia californica* (s) *Ceanothus oliganthus* (s)	*Quercus berberidifolia* (s) *Salvia apiana* (p)	*Malosma laurina* *Xylococcus bicolor** *Salvia mellifera*
S2	*Artemisia californica* (p) *Salvia mellifera* (p) *Malosma laurina* (p) *Baccharis pilularis* (s) *Avena* spp., *Bromus* spp., etc. (s)		*Rhus integrifolia* *Malacothamnus fasciculatus* *Eriogonum fasciculatum** *Lotus scoparius*

For each polygon, Table 3 shows the number of species listed as GAP co-dominants which agreed with our field observations, the species listed by GAP but not observed in significant amounts in the field, and species that could have been listed as co-dominants based on their observed abundance.

For all the polygons taken together, 59% of the GAP co-dominants were observed in the field survey in large enough proportions to justify their co-dominant designation. Of the species listed as co-dominants in the primary assemblages, this percentage was 73%, whereas for species listed within the secondary assemblages, only 45% had sufficient abundance to match the predictions. The "correct" listing of GAP co-dominants was more common (61%) in forested or wooded polygons, with primary and secondary assemblage co-dominants confirmed in the field 82% and 42% of the time, respectively. Overall, agreement with GAP was less common in the chaparral and scrub polygons, with 57% of the GAP co-dominants observed in large enough proportions to justify their co-dominant designation, or 64% and 50%, respectively among primary and secondary assemblages.

There were several instances where species listed in either the primary or secondary assemblages were not observed at all in the polygon in our field surveys. In some cases, a taxonomically similar species was found instead. For example, we did not observe *Quercus cornelius-mulleri* K. Nixon & K. Steele (a scrub oak with tomentose hairs on the underside of the leaves) in polygon F2, but did observe *Q. berberidifolia.* In another case, the species listed in GAP did not even exist within San Diego County according to botanical experts, although a closely-related species was found instead in our study. For example, *Arctostaphylos tomentosa* (Pursh) Lindley was not recognized by Beauchamp (1986) as a species found in the county, but *A. glandulosa* Eastw., a similar hairy manzanita with a basal burl, was found in our surveys for polygon W2. In two other cases, a species listed by GAP was not observed in any of the sample elements we surveyed. *Pinus lambertiana* Douglas was not found in the sample elements in polygon F1, although California State Park personnel indicated they thrived at higher elevations within the polygon, away from roads and in areas close to the polygon boundary. In the other case, *Ceanothus cuneatus* was not found in any of the sample elements within polygon C1.

Similar to the experience with *Pinus lambertiana,* observations of polygon areas away from the chosen sample elements suggested that in some cases the elements chosen did not encompass representative vegetation found elsewhere in the polygon. For example, in polygon S1, large portions of roadside areas in the northern part of the polygon were covered with *Salvia apiana* Jepson. However, permission to access those areas was not granted and no sampling could be performed. In polygon C2, large portions of north-facing slopes in the southern part of the polygon were covered by continuous stands of *Quercus berberidifolia,* but permission was not granted to access those areas. Although unavoidable, these experiences indicate limits to the representativeness of our sampling protocol.

Conversely as noted above, numerous species within the polygons were observed in high enough abundance to warrant possible designation as a co-dominant although they were not listed in the GAP database (Table 3). The abundance of most of these species was modest, but given the SE interval about the mean sampled composition (Table 2), these species could be designated as co-dominants. Most of these species omitted from GAP were shrubs (e.g., *Arctostaphylos glandulosa, Quercus berberidifolia, Ceanothus palmeri* Trel., *Eriogonum fasciculatum* (Benth.) Torrey & A. Gray), except for *Pinus jeffreyi* Grev. & Balf. in polygon F1 and *P. coulteri* D. Don in polygon F2. Many (15 of 27) of these potential co-dominants were listed as co-dominants in *neighboring* GAP polygons (see Table 3), suggesting the influence of adjacent polygons on species composition of the surveyed polygons.

Crown closure. Table 4 summarizes the predicted and measured crown closure for the GAP polygons studied. When the GAP-predicted crown closure of both primary and secondary assemblages were the same, the measured crown closure was within both ranges (polygons F1, C1, and S1). When the GAP-predicted crown closure of both primary and secondary assemblages were different, the measured crown closure was within the crown closure range of one of the assemblages (polygon F2) or between the ranges of both assemblages (polygon W1).

Table 4. Predicted and Measured Crown Closure for Selected GAP Polygons.

Polygon	Primary or secondary	Predicted crown closure (%)	Measured crown closure (%) (c)	(c − 2SE, c + 2SE)
F1	P	60–100	72	(54, 90)
	S	60–100		
F2	P	40–59	54	(44, 63)
	S	60–100		
W1	P	25–39	42	(20, 63)
	S	60–100		
W2	P	60–100	56	(35, 76)
	S	60–100		
C1	P	60–100	81	(63, 99)
	S	60–100		
C2	P	60–100	74	(66, 83)
	S	60–100		
S1	P	40–59	54	(36, 72)
	S	40–59		
S2	P	60–100	63	(45, 80)
	S	25–39		

Discussion

Species composition within the GAP database. In our study, the apparent accuracy of the GAP database was high for forest/woodland species and lower for scrub/chaparral species. As noted earlier, the accuracy of the GAP database is linked to the accuracy of VTM and soil vegetation maps, and to more recent remote sensing data used to create this database. The original VTM and soil-vegetation maps may have been quite accurate for forests and woodlands because of the ease of conducting studies in those relatively open areas, combined with the economic incentive of producing accurate data for these potential timber sources. Scrub and chaparral have little or no commercial value and the effort required to maneuver through dense thickets discourages data collection.

For certain chaparral species, successional changes may explain some of the discrepancies in species composition between the GAP database and the present field study. Although previous studies estimating natural cover of vegetation for BHC inventory generation assumed little change in chaparral vegetation over time (Winer et al. 1983), this assumption may not be appropriate. Chaparral follows certain successional trends after fires (Hanes 1971; Keeley 1975; Hanes 1977; Barbour and Major 1977; Gordon and White 1994). *Ceanothus* chaparral and coastal sage scrub may emerge immediately after a fire depending on the elevation, aspect, and antecedent vegetative conditions, but may be displaced by chamise or scrub oak chaparral. *Ceanothus cuneatus* (Hook.) Nott. is one species which within 50 years can die out completely, and *C. leucodermis* E. Greene is eliminated after 40 years. Other species of *Ceanothus* tend to thin with time because recruitment of new individuals does not occur in the absence of fire. Some of the more underrepresented species in our field observations which were predicted by the GAP database were members of the genus *Ceanothus* (*C. leucodermis, C. oliganthus* Nott., *C. greggii,* A. Gray and

C. cuneatus). A successional process could explain the absence of *Ceanothus* species from some of the field data even though they were predicted in the GAP database.

However, explaining discrepancies in the chaparral and coastal sage scrub polygons is still at present speculative. Direct evidence for successional trends in chaparral and coastal sage scrub species is not readily available in the literature for San Diego County, nor can it be easily determined. Establishing successional trends requires knowing the species composition at historical times (as well as at present) and such historic information is not readily available for specific locations within San Diego County. It would be useful to re-examine the VTM plots for chaparral and coastal sage scrub and compare them to the VTM plots for blue oak woodlands evaluated by Allen-Diaz (1993) and to the fire maps compiled by the California Department of Forestry and Fire Protection. However, such evaluation was beyond the scope of this project.

Within forests and woodlands, studies have evaluated the accuracy of VTM plots over time. For example, Allen-Diaz (1993) found little natural change in species composition in VTM plots within blue oak woodlands in the Central Valley but some increase in the size and number of oak species individuals over a period of 50–60 years. Minnich et al. (1995) reported gradual species change in VTM plots within the San Bernardino Mountains from *Pinus ponderosa* Laws. and *P. lambertiana* to *Abies concolor* (Gordon & Glend.) Lindley and *Calocedrus decurrens* (Torrey) Florin attributable to fire suppression. Some of these changes were attributable to effects of air pollution on beetle-induced mortality and seedling recruitment of pine species (Miller et al. 1997). However, these studies did not report wholesale replacement of species within forested and wooded VTM plots.

Other discrepancies observed between GAP predictions and data from the surveyed sample elements could be attributed to the GAP database. For example, the GAP database predicted species which are not recognized by local botanists as present in the county. Some of these discrepancies appear to be due to taxonomic distinctions (*Arctostaphylos tomentosas* listed by GAP in place of *A. glandulosa* or *Quercus cornelius-mulleri* listed by GAP in place of *Q. berberidifolia*). Fortunately, these discrepancies may have little impact on the utility of the GAP database for use in assembling BHC emission inventories because taxonomically-related species were found instead. We have shown that taxonomy can be a strong predictor of BHC emission rates, especially at the genus level (Benjamin et al. 1996).

Despite the discrepancies between predicted and observed plant species cover, on average the utility of the GAP database for developing BHC emission inventories appears to be adequate. Even though some plant species predicted by the GAP database were not present or were present at lower levels than expected for a co-dominant species, these discrepancies will not necessarily translate into significant errors in BHC emission inventories. For the purpose of the development of such BHC emissions inventories, species composition errors have adverse effects only when a plant species listed in GAP as a co-dominant for a polygon should actually be a species with a significantly different measured BHC emission rate. For example, if a co-dominant listed by GAP is a high isoprene-emitting species, but the actual plant species which occurs in the polygon is a low- or non-emitting species, the resulting BHC emission flux calculated for that polygon will over-estimate isoprene emissions. In contrast, for cases where a low-emitting species occurs in place of another low-emitting species (for example, *Adenostoma fasciculatum* in place of *Cercocarpus betuloides* Torrey & A. Gray), the error may be significant with respect to correct species assignment in GAP, but have minimal effect on the resulting BHC emissions inventory.

In order to evaluate the significance of species discrepancies between the GAP listings and the field surveys, the indices identifying the polygons with the largest biogenic hydrocarbon emissions based on GAP (see above) were recalculated for the eight polygons investigated in this study using the observed percent covers of plant species within each polygon. Values of the indices were calculated by summing the isoprene or monoterpene emission rates of the plant species in a given polygon, weighted by their percent relative cover, and multiplying this sum by the area of the polygon. For all eight polygons, total isoprene emission and total monoterpene emissions were calculated based on the survey data, and these were compared with the totals generated during the polygon selection phase of the study based on the GAP data. Although for some individual polygons the discrepancy between the indices obtained for GAP species vs observed species was quite large, when summed over all eight polygons the differences in the total emission indices were negligible. Thus, the total isoprene emission for the eight polygons based on the survey data was only 7% greater than the total calculated using the GAP data, while the total monoterpene emission for the eight polygons based on the field survey data was just 2% lower than the GAP derived total. Clearly, the GAP GIS database can be a useful source of species composition and dominance information for the purpose of assembling BHC emission inventories when a sufficiently large number of polygons are averaged.

Finally, the observation of numerous species in high-enough abundance to be designated as co-dominants but not listed in the GAP database is to be expected given that GAP designates only six co-dominants per polygon, three in the primary assemblage and three in the secondary assemblage. A species assemblage with only three co-dominants may not necessarily capture the species composition within a polygon.

Limitations in the present GAP field assessment. Our survey data indicated a difference in the accuracy of primary versus secondary assemblages in GAP. Primary assemblage co-dominants were correctly listed by the GAP database more often than secondary assemblage species. In a GAP polygon, primary assemblages by definition are more prevalent. In the present study, a sample element was more likely to be placed in the more prevalent assemblage, resulting in the gathering of more data on primary assemblage species and higher representation by those species. With use of only three or four elements, there was a smaller chance of sampling a species from a secondary assemblage with a frequency proportional to the area occupied by that assemblage. In a study with more resources, and hence a larger number of randomly-placed sample elements, representation by species from either assemblage should be proportional to that assemblage's cover within the polygon.

Limitations in siting the sample elements may have accounted for other discrepancies as well. By sampling only near roads, away from polygon boundaries, and only with the permission of land owners, large areas were removed from inclusion in the study. These limitations were recognized and accepted as a condition to performing this type of survey. Observations from a distance and input from individuals knowledgeable about local botany were helpful in identifying additional plant species outside the selected sample elements but did not add to the quantitative characterization of vegetation cover reported here.

As noted earlier, the GAP assessment in San Diego County posed special problems in terms of sampling representative areas within privately-owned parts of a polygon. In the Utah GAP validation project, 42% of the state was under the control of the US Bureau of Land Management, with private interests owning only 21% (Edwards et al. 1995). In San Diego County, the San Diego County Association of Government (SANDAG) 1990 ownership database indicated private interests owned 41% of county land (SANDAG 1997). Private land owners typically purchase land in accessible areas within the vicinity of roads, and therefore, suitable public lands within the vicinity of roads for the purposes of conducting a GAP assessment were limited. Although a 14% success rate for our mailers seeking property access was high by the standards of some surveys, obtaining permission to access private property was a limiting factor in being able to site sample elements.

These access limitations present possible biases related to not being able to survey private lands. Observations from roadsides and hilltops suggested that land use on private lands in the areas investigated did not differ appreciably from land use on public lands in these areas. Nevertheless not being able to survey more private lands resulted in potential sampling bias from this constraint on selecting random sample elements. For example in polygons C2 and S1, certain areas were removed from the random selection process due to private ownership. If such areas had been available for sampling and could have been included in the random selection process, better correlation between survey data and the GAP database might have been observed.

Additional potential biases exist due to sampling only eight of the original 437 GAP polygons within western San Diego County. However, the sample size for our purposes was relatively large, since the eight polygons studied were selected from a subset of 40 polygons believed to be the highest isoprene or monoterpene emitting polygons, respectively. Thus, high-emitting polygons were well represented. Although a bias existed for undersampling the low-emitting polygons, the likelihood of low-emitting polygons actually being high-emitting polygons was not significant since a relatively small number of plant species are high-emitting (Benjamin et al. 1996).

Given the effort needed to gather the field data, it was necessary to reduce the area sampled. Moreover, the sample area required to estimate the true relative cover of individual species in a polygon was not known. The literature suggested surveying 7% of a forested area using parallel belt transects provided a 65% chance the sample mean of the basal area of the trees would be within 10% of the true mean for more common species (Bormann 1953). The effort needed to obtain an accurate measure of relative cover may be similar. In the present study, the belt transects directly sampled 1.8 hectares within polygons of about 1800 to 2300 hectares, or about 0.1% of the polygon area. The line transects approximating 3 m belt transects directly sampled 0.72 hectares in polygons ranging in size from 3600 to 6600 hectares, or about 0.01%. On the other hand, the effective size of our samples may be larger. The vegetation cover composition within the transects may approximate the cover composition of a square which immediately bounds the ends of the perpendicular transects. If this was the case, the three sample elements in each forest/woodland polygon may have effectively sampled 75 hectares or about 4% of the polygon area, while the four sample elements in the chaparral/scrub polygons may have effectively sampled 36 hectares or about 1% of the polygon area.

A more intensive sample design could have allowed the surveying of plants that were missed in the current surveys. The anecdotal comments about the existence of *P. lambertiana* at higher elevations in polygon F1 suggest a more intensive sampling effort could address these omissions. Although large sample elements avoids quantifying heterogeneity below the intended resolution of the map, using large sample elements given finite time and resources results in oversampling certain areas at the expense of undersampling other areas. An alternative using shorter transects or recording data along regular intervals (e.g., recording data along 50 m for every 100 m) could result in less time being invested per survey element, allowing for the inclusion of more survey elements. However, constraints resulting from the lack of permission to access certain properties make this option difficult to freely implement.

Conclusions

A ground-based assessment of the GAP database for San Diego County for the purpose of evaluating its utility in the development of BHC inventories revealed the database was a useful source for data on species composition and abundance. The species listed by GAP accounted for two-thirds to three-quarters of the relative cover in selected polygons. About 60% of the species listed by GAP were found in high enough proportions in the field surveys to justify their listing. For certain species listed in GAP but not found in high abundance in the field surveys, taxonomically similar species were found. Discrepancies between the field observations and the GAP database could be explained by inaccuracies of the initial data sources incorporated into GAP, successional changes, limitations in sampling design, the arbitrary limiting of GAP to six species per polygon, and bias in sample site selection towards areas accessible by roads and public ownership. Nevertheless, overall comparisons between the BHC emission indices calculated using GAP data and the corresponding BHC emission indices calculated based on our field survey plant cover data indicate the utility of the GAP database in the development of BHC emission inventories.

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